Relationship of heart rate and electrocardiographic time intervals to body mass in horses and ponies

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Abstract: OBJECTIVES: To investigate the relationship of heart rate (HR) and ECG time intervals to body weight (BWT) in healthy horses and ponies. We hypothesized that HR and ECG time intervals are related to BWT. ANIMALS: 250 healthy horses of >30 breeds; 5.5 (1-30) y [median (range)]; 479 (46-1018) kg. METHODS: Prospective study. Standard base-apex ECGs were recorded while the horses were standing quietly in a box stall. Mean HR over 15 s was calculated and RR interval, PQ interval, QRS duration, and QT interval were measured by a single observer.QT was corrected for differences in heart rate using Fridericia's formula (QT(cf) = QT/(3)√RR). The relationship between ECG variables and BWT, age, sex, and RR interval was assessed using multivariate backward stepwise regression analyses. Goodness of fit of the model was improved when using log(BWT) compared to BWT. Body weight was overall the strongest predictor of HR and ECG time intervals. Therefore, only log(BWT) was included as an independent variable in the final model. The level of significance was p = 0.05. RESULTS: HR (R(2) = 0.21) showed a significant negative relationship and PQ (R(2) = 0.53), QRS (R(2) = 0.23), QT (R(2) = 0.14), and QT(cf) (R(2) = 0.02) showed significant positive relationships to log(BWT). CONCLUSIONS: Small equine breeds undergoing routine ECG recordings have slightly faster heart rates and shorter ECG time intervals compared to larger equine breeds. Although the magnitude of absolute differences may be small, body weight needs to be considered among other factors when comparing HR and ECG time intervals to normal ranges in horses.

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Relationship of Heart Rate and Electrocardiographic Time Intervals to Body Mass in Horses and Ponies

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ABSTRACT

Objectives – To investigate the relationship of heart rate (HR) and ECG time intervals to body weight (BWT) in healthy horses and ponies. We hypothesized that HR and ECG time intervals are related to BWT.

Animals – 250 healthy horses of >30 breeds; 5.5 (1-30) y [median (range)]; 479 (46-1018) kg.

Methods – Prospective study. Standard base-apex ECGs were recorded while the horses were standing quiet in a box stall. Mean HR over 15 sec was calculated and RR interval, PQ interval, QRS duration, and QT interval were measured by a single observer. QT was corrected for differences in heart rate using Fridericia's formula ($QT_{cf} = QT / \sqrt[3]{RR}$).The relationship between ECG variables and BWT, age, sex, and RR interval was assessed using multivariate backward stepwise regression analyses. Goodness of fit of the model was improved when using log(BWT) compared to BWT. Body weight was overall the strongest predictor of HR and ECG time intervals. Therefore, only log(BWT) was included as an independent variable in the final model. The level of significance was p=0.05.

Results – HR (R^2=0.21) showed a significant negative relationship and PQ (R^2=0.53), QRS (R^2=0.23), QT (R^2=0.14), and QT_{cf} (R^2=0.02) showed a significant positive relationship to log(BWT).

Conclusions – Small equine breeds undergoing routine ECG recordings have slightly faster heart rates and shorter ECG time intervals compared to large equine breeds. Although the magnitude of absolute differences may be small, body weight needs to be considered among other factors when comparing HR and ECG time intervals to normal ranges in horses.

INTRODUCTION

A negative association between body weight (BWT) and heart rate (HR) has been observed across a wide range of mammalian species.[1-3] Furthermore, it is well known that electrocardiographic (ECG) time intervals vary with heart rate and body weight.[3-6]

However, the association of HR and BWT within a single species containing a wide spectrum of large and small breeds is less clear and still under debate. Contrary to commonly stated clinical experience, the results of two recent studies indicated that there is no significant association between HR and BWT in apparently healthy dogs.[7,8] However, in one of these studies evaluating 24-h ambulatory ECG recordings of 60 healthy dogs between 2 and 80 kg BWT, a strong trend towards a negative association between average HR and BWT ($p=0.06$) was reported.[8]

Within the equine species, small breeds are generally thought to have higher heart rates than large breeds. Historical data compiled from a variety of electrocardiographic and hemodynamic studies[9-27] on a total of 484 horses and ponies suggests that small breeds have a slightly higher resting heart rate compared to large breeds and draft horses, although some of the data were inconsistent (Fig. 1). However, despite the clinical importance of heart rate and the large differences in size among different equine breeds, there is little specific information about normal heart rates and ECG time intervals in horses and ponies in relation to body size.

The goal of this study was therefore to investigate the relationship of HR and ECG time intervals, respectively, to BWT in apparently healthy horses and ponies and to calculate weight-based normal ranges for all variables.

ANIMALS, MATERIALS AND METHODS

Study population

The study population was chosen prospectively from the hospital population at The Ohio State University Veterinary Teaching Hospital and at the Vetsuisse Faculty of the University of Zurich. All horses were aged ≥ 1y and considered healthy based on history and physical examination, including careful auscultation of heart and lungs. Animals resisting the procedure or showing nervous behavior were excluded from the study.

Two-hundred and fifty horses (96 female, 46 male, 105 male castrated, 3 not recorded) with an age of 5.5 (1-30) years [median (range)] and a body weight of 479 (46-1018) kg were included in the study. The study population included 43 draft horses (Percheron, Belgian, Clydesdale, Shire, Irish, mixed draft); 20 warmblood horses (Oldenburg, Hanoverian, Holstein, Dutch, Polish, Swedish); 36 Thoroughbreds; 30 Standardbreds; 49 Quarter horses, Paint horses and Appaloosas; 40 small breed horses (miniature horse, Pony of the Americas, Icelandic horse, Shetland pony); and 32 other breeds (Arabian, American Saddlebred, Missouri Fox Trotter, Paso Fino, Morgan horse, Tennessee walker, Tinker, Argentinian, Haflinger, mixed breed).

All animals received adequate human care and were treated during the examination according to the ethical guidelines of the universities.

Electrocardiographic recordings

Physical examinations and ECG recordings were performed by a variety of different observers. During the procedures, all horses were unsedated, standing quiet in a box stall, gently restrained by experienced handlers. ECG leads with alligator clips were placed to obtain a standard base-apex lead. After an accustoming period of approximately 1 minute, a 15 second ECG was recorded and printed on thermosensitive paper using a multiparameter physiologic monitor[a]. Paper speed was set at 50 mm/s (n=246) or at 25 mm/s (n=4).

Rhythm analysis and measurements

Rhythm analysis and measurements of ECG time intervals were performed by a single observer (MK) using the original paper prints. Occurrence of vagal arrhythmias (ie, marked sinus arrhythmia, sino-atrial (SA) block, second-degree atrioventricular (AV) block) or other rhythm events was recorded. Mean heart rate ($HR_{15''}$) during recordings was calculated by multiplying the number of QRS complexes recorded over 15 seconds by factor 4. The following ECG time intervals were subsequently measured: RR interval, PQ interval, QRS duration, and QT interval. The QT interval was corrected for differences in heart rate using Fridericia's correction ($QT_{cf} = QT / \sqrt[3]{RR}$; RR being the RR interval immediately preceding the respective QT interval).

Three consecutive cardiac cycles were measured for each horse and averaged for further analyses. Cycles immediately following an incident of 2nd degree AV block were excluded from analyses.

Data analysis and statistics

Graphical presentation, data analyses, and statistics were performed using commercial computer software[b,c,d]. Summary statistics of age and body weight were calculated and reported as median (range).

Multivariate backward stepwise regression analyses were then performed, including HR and ECG time intervals, respectively, as dependent variable and BWT, age, sex, and RR interval (the latter was included for ECG time intervals only) as independent variables. Breed or breed groups were not included in the models because of their strong relationship to body weight (collinearity). Individual temperament and demeanor as well as athletic condition of the horses were not included in the models because of lack of objective measures of these factors. Validity of the normality assumption was confirmed by assessment of histograms and normal probability plots of the residuals.

Body weight was overall the strongest predictor of HR and ECG time intervals. For all variables except QT interval, inclusion of age, sex, and RR interval in the model did not markedly increase the coefficient of determination (absolute increase of $R^2 < 0.047$; data not shown). For QT (but not QT_{cf}), inclusion of RR improved R^2 from 0.144 to 0.331, which was expected because of the well known rate dependence of the QT interval.[9,10,28] Goodness of fit of the model, assessed using the Akaike's Information Criterion, was improved after log transformation of BWT. Based on these preliminary analyses, only log(BWT) was included as an independent variable in the final models. The results of the regression analyses were graphically displayed by scatter plots including the regression line and the 95% confidence band of the regression line. The coefficient of determination (R^2) was reported. The normal ranges of HR and ECG time intervals in relation to BWT were graphically displayed by the 95% prediction band. The level of significance was set at $p = 0.05$.

RESULTS

The majority of the horses were in regular sinus rhythm (NSR) during the examination. Fifteen horses (6 %) showed arrhythmias related to high vagal tone, including marked sinus arrhythmia (n=4; 3 small breeds, 1 Quarter yearling; 5–26 years; 80–109 kg), SA block (n=3; 2 Standardbreds, 1 small breed; 2–9 years; 240–471 kg), and second degree AV block (n=8; 3 Thoroughbreds, 3 Quarter horses, 2 others; 5–16 years; 489–723 kg). One horse had an atrial premature complex (APC) and one horse had two ventricular premature complexes (VPC) during the 15-second recording.

The results of the univariate regression analyses are displayed in Fig. 2 and 3. $HR_{15"}$ showed a significant negative relationship to log(BWT), whereas RR, PQ, QRS, QT, and QT_{cf} showed a significant positive relationship to log(BWT).

DISCUSSION

The results of the current study indicate that in clinical situations such as during standard ECG recording, resting HR is significantly related to BWT in the equine species. This study therefore is in agreement with general clinical experience and with historical data.[9-27] However, the association between HR and BWT is relatively weak. The absolute difference in mean heart rate is only approximately 4 min^{-1} in the weight range between 400 and 700 kg. It increases to 18 min^{-1} when considering a larger range between 50 and 1000 kg. Statistically, only about 21% of the variation in HR can be explained by differences in BWT (when analyzed after log transformation of BWT), whereas the remaining 79% must be explained by other factors or inherent variability. This is not surprising, since resting heart rate in healthy animals is known to depend on a variety of other factors, including age, sex, temperament, athletic condition, and possibly breed.[7,29] While a significant influence of age and sex could not be shown in the present study on horses ≥ 1y of age, the effects of temperament and demeanor, athletic condition, and breed were not evaluated.

Some horses might have been slightly stressed because of the hospital environment, the physical restraint, and the data collection procedure. In fact, the prevalence of second degree AV blocks in this study population (8/240, 3.3%) was markedly lower than reported for horses examined at rest (15-23%)[30-32] and for horses undergoing 24-hour Holter ECG monitoring (up to 44%),[33] possibly indicating some degree of vagal withdrawal and/or sympathetic stimulation. Although stress and excitement could have been reduced by using ambulatory Holter ECG or telemetric ECG monitoring, it should be noted that this study more closely reflects the real clinical situation and is therefore representative for the findings obtained during standard medical procedures. One might argue that ‘cold blooded’ giant breed horses have a more stolid demeanor and are generally calmer than average size sports horses, thereby explaining their slightly lower resting heart rate in larger horses. However, the same might also be true for some small breed horses. Interestingly, marked sinus arrhythmia and SA block were only observed in horses between 80 and 471 kg BWT and second degree AV blocks were only observed in horses between 489 and 723 kg BWT. This finding could indicate that vagal influence is most prominent in horses at a weight range of approximately 80 – 720 kg, but may be less pronounced in very small and very large horses. Alternatively, it is possible that vagal influence in heavy draft horses preferentially causes slowing of regular sinus node depolarization rather than SA or AV block. Based on the available information, the influence of weight- or breed-related differences in temperament cannot be conclusively determined, all the more considering that individual variation in character independent of body size is certainly quite large.

Athletic condition certainly differs in relation to breed and use of the horses. Small breed horses (unlike Thoroughbreds, Standardbreds, Quarter horses, and Warmblood horses) are often not in athletic condition and therefore may have a slightly higher resting heart rate. However, this may also apply for many giant breed horses, which however, according to the present study, do have even lower resting heart rates than medium sized horses. Therefore, population wide differences athletic condition probably cannot explain the weight dependence of HR found in this study.

In mammals, the specific metabolic rate (ie, the metabolic rate per unit mass) decreases with increasing body size. Hence, energy metabolism is higher in small compared to large mammals.[34] This has been linked to the inverse relationship between HR and BWT among mammals, since the increased relative need for oxygen and blood flow in the small animal is not achieved through a relatively larger heart or stroke volume, but through an increase in heart rate.[35] However, there are some data suggesting that energy metabolism might not be inversely related to body weight within the equine species.[36,37] Hence, differences in specific metabolic rate might not explain the weight dependence of HR in horses and ponies. It has been speculated that differences in sinus node dimensions and the increased coupling of autonomic cells in bigger pacemakers may explain the association of body size to HR in mammals.[38] But the same authors also pointed out that differences in HR between individuals of the same species and age can be quite large, probably as a result of different sets of membrane currents.[38] Yet another group of researchers found that the resting heart rate in mammals might be optimized for pulsatile blood flow in large arteries and therefore is inversely related to body size.[39] In any case, the reasons for the inverse relationship of HR and BWT within the equine species remain largely speculative and it is unknown, whether the explanations that have been formulated for interspecies relationships of HR and BWT in mammals are also applicable to a single mammalian species.

This study also revealed a significant direct relationship between BWT and ECG time intervals. In agreement with previously reported data in horses and ponies,[9-12,40-42] the strongest associations were found between BWT and PQ interval and between BWT and QRS duration. It was not surprising to find that QT interval was not only related to body weight but also to the preceding RR interval.[9,10,28] Fridericia's formula was used exemplarily to eliminate the influence of HR on QT interval in this study. However, rate correction of QT interval is difficult and there is no general consensus on the best formula to use. Many different methods of correction have been proposed for different species and under different conditions.[43-45] In this study, we did not further explore the rate dependence of the QT interval in horses. It is therefore possible that a different method of correction would have been more appropriate or that different methods would have been required for different sex, age, breed or even for individual horses.[9,44,45] Nonetheless, it was interesting to find that QT_{cf} was nearly independent of BWT, suggesting that most of the differences in QT were indeed related to differences in HR, but not to differences in BWT.

As a limitation of this study, general health was determined based on history and physical examination only. No advanced diagnostic methods were used to confirm absence of cardiovascular disease. Therefore, some horses included in the study might have suffered from subclinical, mild cardiovascular disease. In fact, two horses showed atrial and ventricular premature complexes, respectively, possibly indicating cardiac compromise. However, since occasional premature complexes can be observed even in apparently healthy horses,[46-48] this finding is inconclusive. These two horses, that were considered healthy based on medical history and physical examination, were therefore not excluded from the study. Because of the large number of horses in the study population, the error introduced by a few horses possibly suffering from subclinical cardiac disease was considered minor.

CONCLUSIONS

In conclusion, the present study shows that in clinically healthy horses undergoing routine ECG recordings there is a significant, although weak inverse relationship between HR and BWT. Hence, when observed on a population level, small equine breeds tend to have slightly faster heart rates compared to large breeds. Similarly, there is a significant, but mostly weak direct relationship between BWT and PQ, QRS, QT, and QT_{cf} intervals. The strongest association was found between BWT and PQ interval, whereas QT_{cf} was nearly independent of BWT. Body weight might have to be considered as one of the determinant factors when interpreting HR measurements and ECG recordings in individual patients under clinical conditions.

FOOTNOTES

[a]Datascope Passport, Datascope Passport, Fumedica AG, Muri, Switzerland.

[b]Microsoft Office Excel 2007, Microsoft Corporation, Redmond, WA.

[c]GraphPad Prism v5.04 for Windows, GraphPad Software, San Diego, CA.

[d]SigmaStat v3.5, SPSS Inc, Chicago, IL.

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CONFLICT OF INTEREST

No conflicts of interest to disclose.

FIGURES

Figure 1: Heart rates reported in electrocardiographic and/or hemodynamic studies on a total of 484 horses and ponies, grouped by breed.[9-27] Each dot represents the mean heart rate reported in the respective studies.

Figure 2: Results of the univariate regression analyses. *Left:* Semi-logarithmic (lin-log type) scatter plots including the regression line and the 95% confidence band of the regression line. *Right:* Non-logarithmic scatter plots including the regression line and the 95% prediction band. Normal ranges for HR and ECG time intervals for a specific BWT can be estimated based on the prediction band.

R^2, coefficient of determination; $HR_{15''}$, mean heart rate calculated over 15 seconds.

Figure 3: Results of the univariate regression analyses. *Left:* Semi-logarithmic (lin-log type) scatter plots including the regression line and the 95% confidence band of the regression line. *Right:* Non-logarithmic scatter plots including the regression line and the 95% prediction band. Normal ranges for HR and ECG time intervals for a specific BWT can be estimated based on the prediction band.

R^2, coefficient of determination; RR, RR interval; PQ, PQ interval; QRS, QRS duration; QT, QT interval; QT_{cf}, rate-corrected QT interval (Fridericia's correction).

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Figure 1

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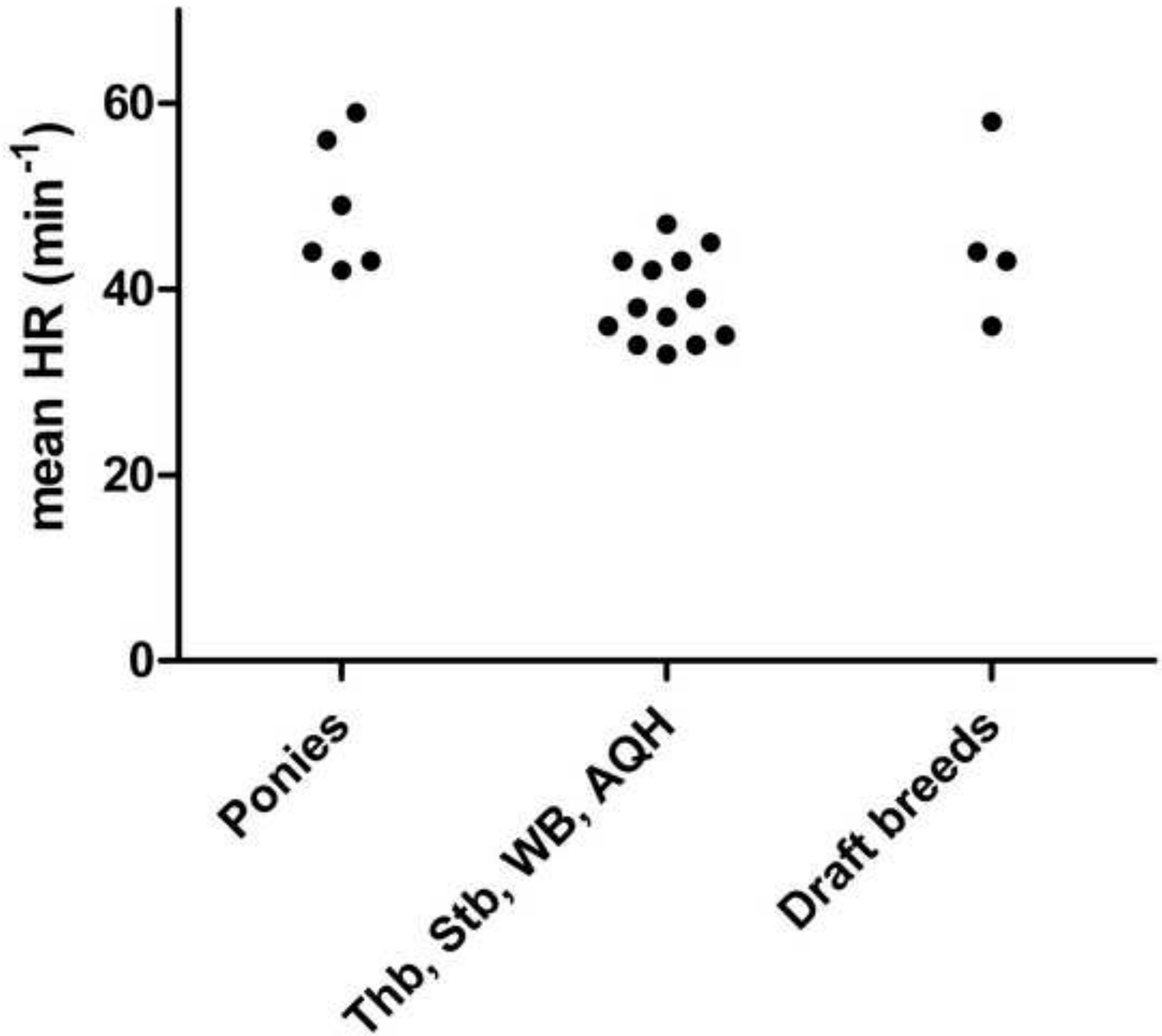

Figure 2
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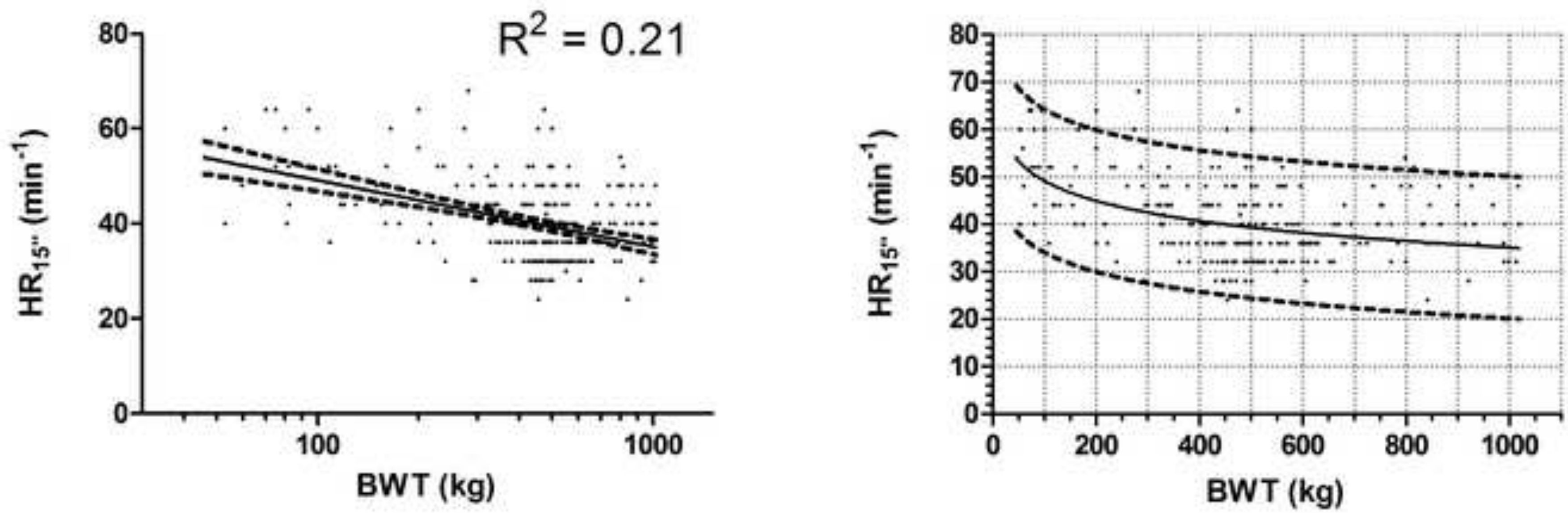

Figure 3

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